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The effect of aluminum on the emission spectra of solid propellants in the 7.5 to 15.0 micron region.

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THE EFFECT OF ALUMINUM ON THE EMISSION
SPECTRA OF SOLID PROPELLANTS IN THE
7.5 TO 15.0 MICRON REGION

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THE EFFECT OF ALUMINUM ON THE EMISSION SPECTRA OF SOLID
PROPELLANTS IN THE 7.5 TO 15.0 MICRON REGION

by

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ABSTRACT

The effect of aluminum in solid propellants on the emission of combustion energy in the 7.5-15.0 micron region of the infrared spectrum was measured. The presence of an "atmospheric window" (8.0-13.0 microns) allows energy in this region to be transmitted over long atmospheric paths with minimal attenuation. The 7.5-15.0 micron spectra of three propellants, similar in composition except for aluminum content, were recorded on an oscillogram. The deflection of the oscillogram at certain wavelengths was then compared to the oscillogram of a 600°C blackbody. The apparent spectral radiance for each propellant at these wavelengths was then computed. Results indicated that in the aluminized propellants a relatively intense band occurred at about 10.3 microns. No evidence for such a band was found in the control propellant which contained no aluminum. Results also showed that the intensity of the H_2O band was inversely proportional to the aluminum content of the propellant.

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TABLE OF SYMBOLS AND ABREVIATIONS

μ microns (one $\mu = 10^4$ Å $= 10^{-4}$cm, or 10^4 cm^{-1})

λ wavelength

mv   millivolts

CVF   circular variable filter (neutral density)

cps   cycles per second

T_1 thermocouple temperature in millivolts of the reference blackbody source (near ambient)

R_λ spectral response of system (spectrometer and external optics)

S_λ^{BB} scaled deflection of the 600°C blackbody at a particular wavelength

N_λ^{BB} spectral radiance of the 600°C blackbody at a particular wavelength

N_λ^{T} spectral radiance of the target at a particular wavelength

S_λ^{T} deflection of the target at a particular wavelength

$\left(\dfrac{S_\lambda^{T}}{S_\lambda^{BB}}\right)^*$ averaged ratio of deflection of target to scaled deflection of 600°C blackbody at a particular wavelength

$\left(N_\lambda^{T}\right)^*$ apparent spectral radiance of target at a particular wavelength

ACKNOWLEDGEMENTS

1. Introduction

The recent development of sensitive, rapidly responding detectors coupled with the advent of rapid dispersion techniques has made possible the development of rapid scanning infrared (IR) spectrometers. These spectrometers are well suited for the study of transient combustion phenomena such as the combustion of solid propellants.

Unlike the continuous spectrum from a blackbody source, the line emission from hot gases, such as the gases developed in the combustion of solid propellants, is a rapidly varying function of wavelength. Only when the target being examined is optically thick (i.e., exhibits a high linear density of emitting molecules along the observational axis, a condition normally met in high pressure combustion) do the spectral lines overlap to produce a relatively smooth spectral curve (4). The individual spectral emission lines represent energy transitions of molecules which have been raised to excited states during the combustion process and which then return to their ground states. These energy states are discretely spaced; therefore, only certain energy transitions are possible, and a line spectrum is produced (4). The theoretically possible energy states of the molecule may be described mainly in terms of the possible electronic, vibrational, and rotational modes of the molecule. The energy transitions involved in changes of electronic levels, however, are normally large enough to remove these transitions from the infrared region of the spectrum (4).

The majority of solid propellants in use today are organic in composition; thus a large amount of the infrared radiation emitted is from vibrationally excited H_2O and CO_2 molecules formed during the combustion process. If the propellant contains an additive such as aluminum, the oxygen

content of the propellant probably will first be apportioned to the formation of various aluminum oxide species. The oxygen available for the formation of H_2O and CO_2 would therefore be reduced relative to a non-metallized propellant (6). The decrease in the amount of H_2O and CO_2 formed should be observed as a decrease in the energy radiated in the H_2O and CO_2 bands of the IR combustion emission spectrum.

The formation of very intense bands in the spectrum due to emission from the aluminum oxide is unlikely. Aluminum oxide is not a gas at the temperatures encountered in propellant combustion plumes. Most of the Al_xO_y molecular species (x and y small integers) formed in the combustion process would quickly condense to form Al_2O_3 particles. The individual spectral lines arising from these particles would therefore overlap and the shape of the emission spectrum would vary smoothly with wavelength. Some very small particles, however, may radiate characteristic vibrational emission. Even though their relative number may be small, these molecular oscillators may emit a spectral band of greater intensity than a corresponding blackbody. The formation of such an emission band rests on the assumptions 1) that the molecular species formed do not agglomerate together to form larger particles before a significant amount of energy is radiated, and 2) that vibrational equilibrium is not immediately reached.

If the infrared emission from a missile plume is used as a basis for a missile detection system, the effect of atmospheric attenuation on the radiation emitted must be taken into account. The intense emission from vibrationally excited H_2O and CO_2 molecules lies approximately in the same region as the corresponding atmospheric absorption bands (Figure 1). The radiation from these vibrationally excited molecules does not correspond exactly with these bands because the high temperatures

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encountered in the combustion process permit higher rotational transitions (4). Over long atmospheric paths, however, the attenuation due to atmospheric absorption will still be high in these spectral regions. The radiation emitted from aluminum oxides, or from the oxides from other metals which may be present in the propellant (Figure 3), lie in the "atmospheric window" region of the spectrum where little absorption takes place (Figure 2). The scattering encountered in this region is also decreased because the wavelength of the radiation is greater than the mean diameter of any particulate matter in the atmosphere (3). The overall attenuation of radiation in the "atmospheric window" region is therefore considerably lower than the attenuation in the shorter wavelength spectral regions. If a significant amount of the radiation emitted from a missile plume was in this region (especially if the radiation occurred as a narrow band spike), early detection of missiles over long distances might be possible.

A large amount of spectral data on various rocket motors and missile propellants has been collected during the past seven years. A careful search of the literature, most of which is classified, reveals that investigators have been mainly interested in the higher energy spectral regions (6 microns and shorter). Hall made some measurements in the longer wavelength regions, but these were made on the older, double base propellants (2).

The apparent lack of spectral data on aluminized propellants for the 7-15 micron region prompted this investigation. It was felt that even if no significant spectral features were discovered, the experiment could provide spectral radiance data that was lacking about the combustion of solid propellants.
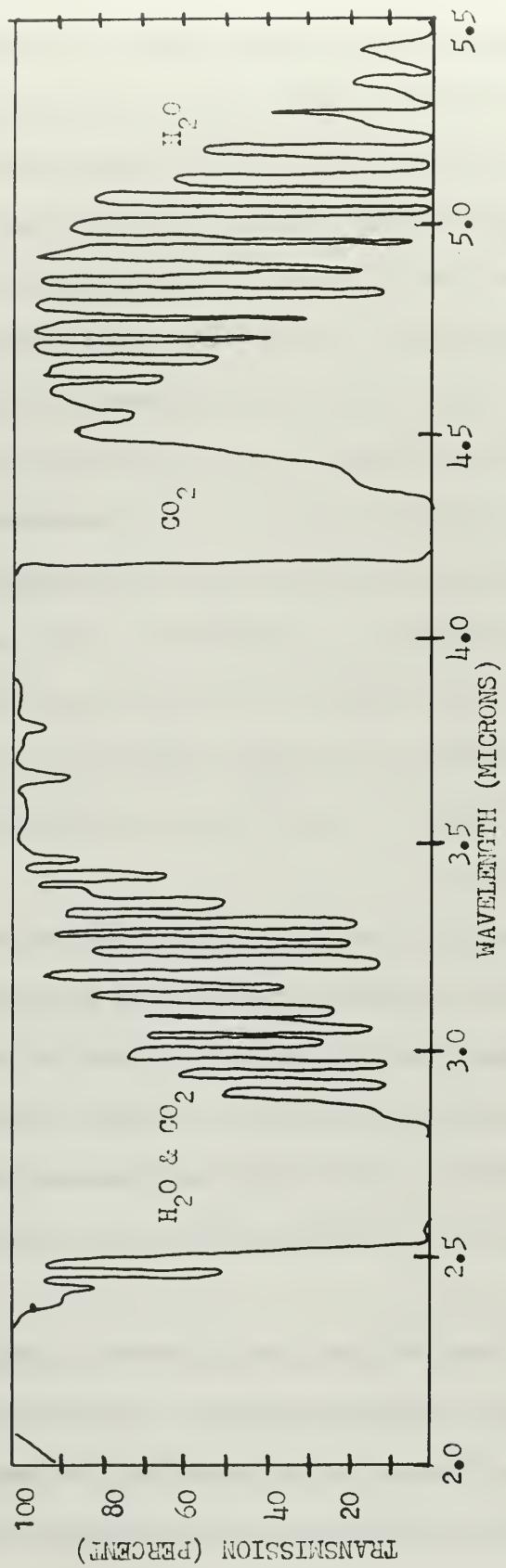
Figure 1

Transmission of the Atmosphere (2.0-5.5 microns)
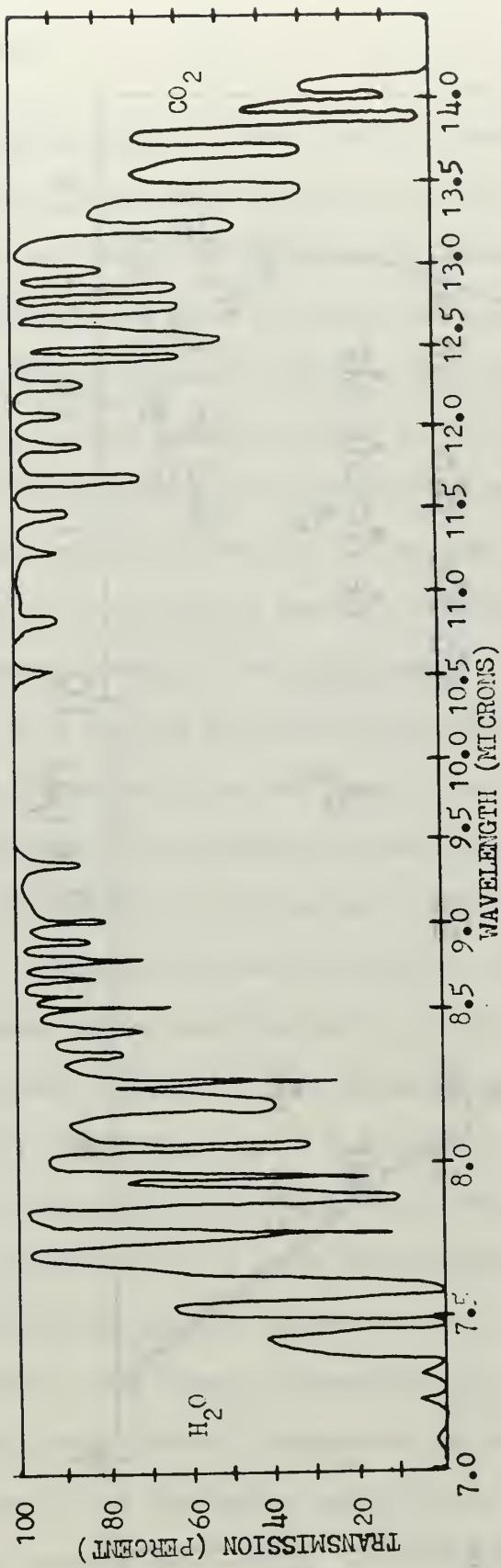
Figure 2

Transmission of the Atmosphere (7.0-14.5 microns)
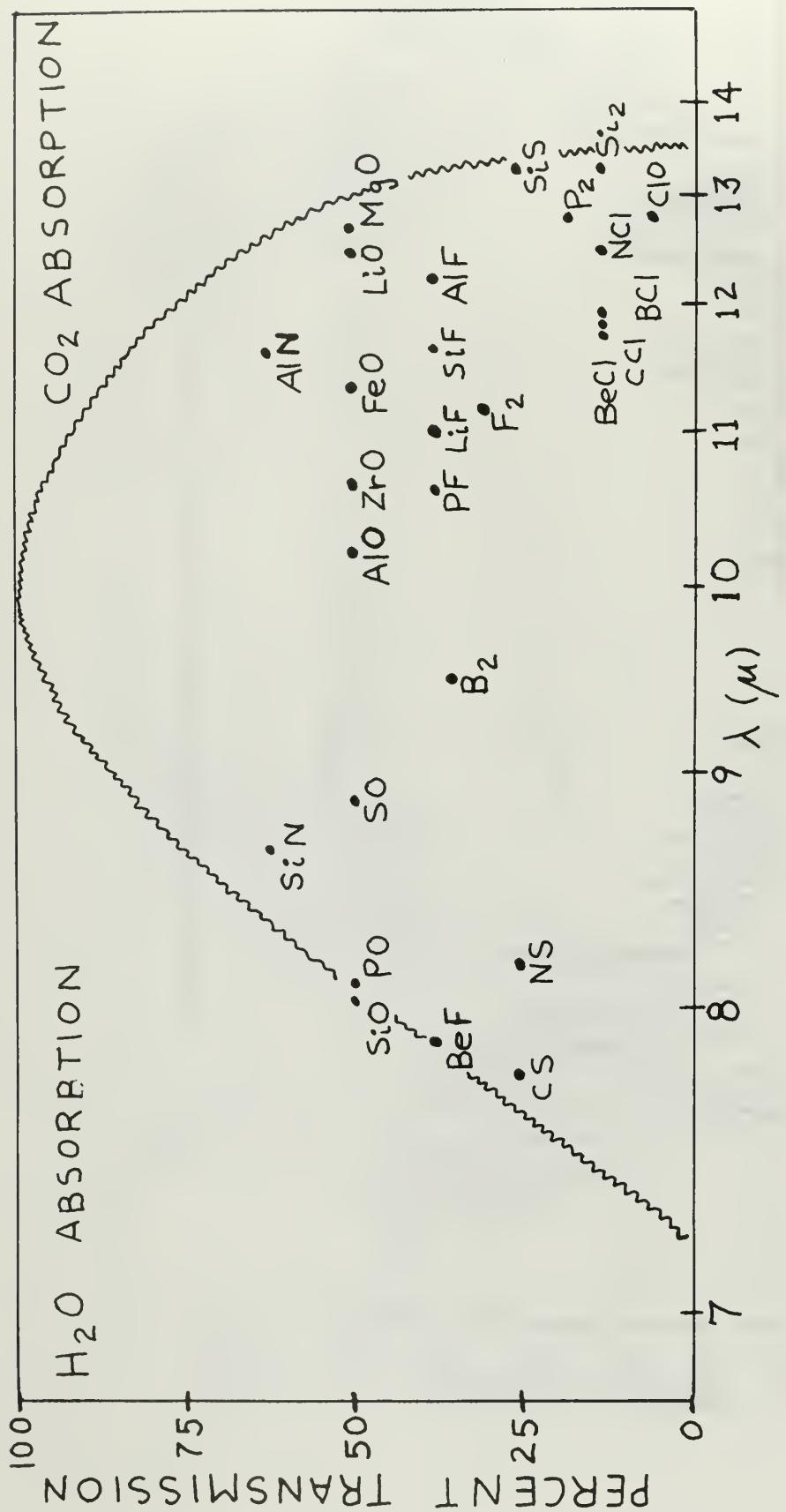
Figure 3

Vibrational Frequencies of Diatomic Molecules in the
IR Atmospheric Window Region

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2. Equipment

a. Spectrometer: A spectrometer constructed by the Naval Ordnance Test Station, China Lake, California was used for the experiment. The instrument was loaned to the Naval Postgraduate School by China Lake. The spectrometer employed a circular variable filter (CVF) to provide the rapid wavelength scan needed for the experiment. The CVF consists of a germanium disc on which layers of dielectric material have been deposited. The thickness of the dielectric coating varies linearly with the angular position of the disc; therefore, each angular position of the filter will pass only a specific wavelength band. The thickness of the dielectric coating is at a minimum at a specified 0° position and increases to a maximum thickness at the 180° position, then decreases to a minimum thickness at the 360° position of the filter. A total of two spectra are therefore scanned with each rotation of the filter (7.5-15-7.5 microns) (Figure 4) (1). Since minor deviations in the thickness of the dielectric coating occur for each side of the filter, the overall spectral response of the spectrometer is not exactly the same for adjacent spectral scans (Figure 5). During operation the CVF is rotated at 1.25 cps, which gives a scanning rate of 2.5 spectra per second. A small steel pin, epoxied to the outer edge of the filter wheel at the 0° (7.5 micron) position, provides a timing pulse for wavelength calibration.

A reflective chopper, operated at 525 cps, is inserted into the optical train. The chopper allows the detector to alternately view the target and a near ambient temperature blackbody source (Figure 7). The temperature of the blackbody source (T_1) is monitored with a copper-constantan thermocouple and may be varied within small limits.

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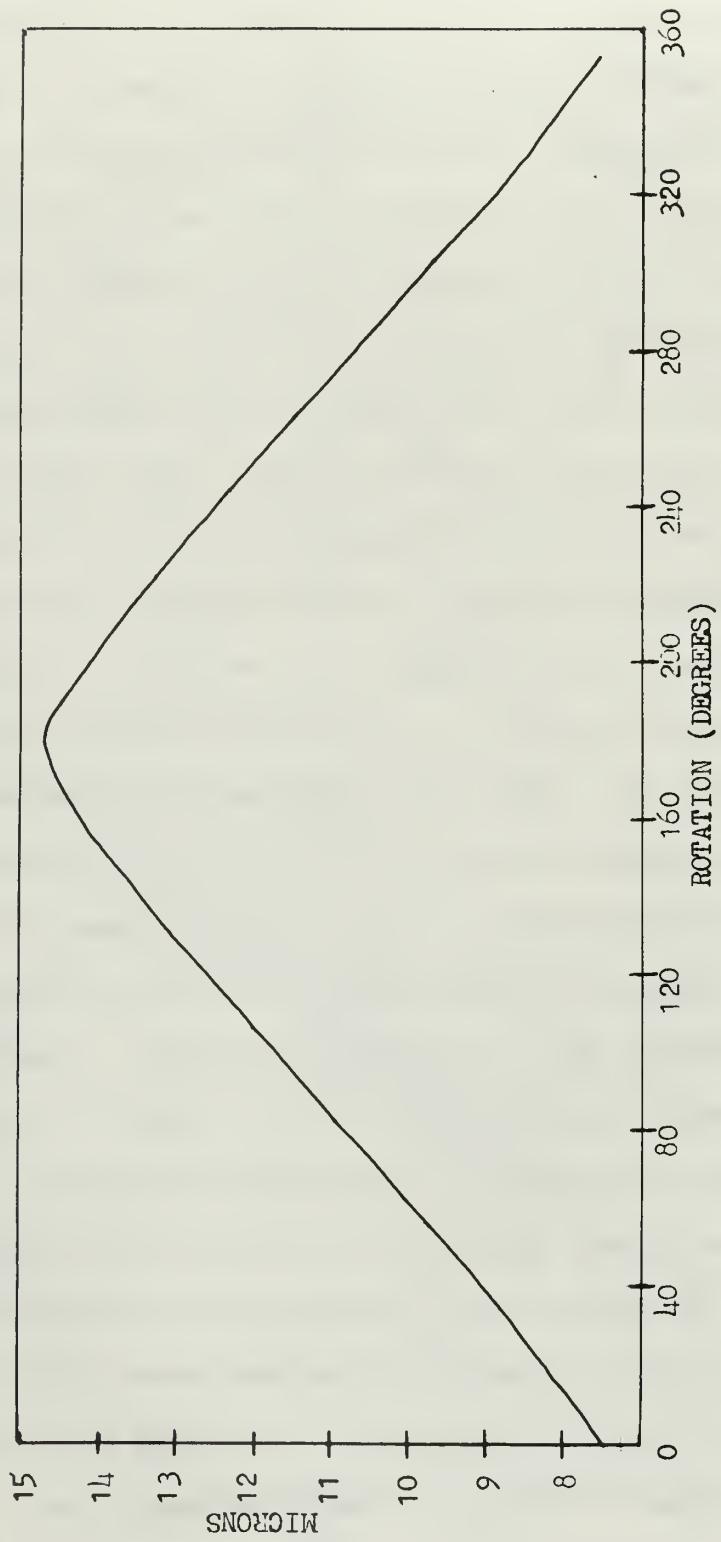
Figure 4

Measurement of Wavelength as a Function of
Rotational Angle for the CVF
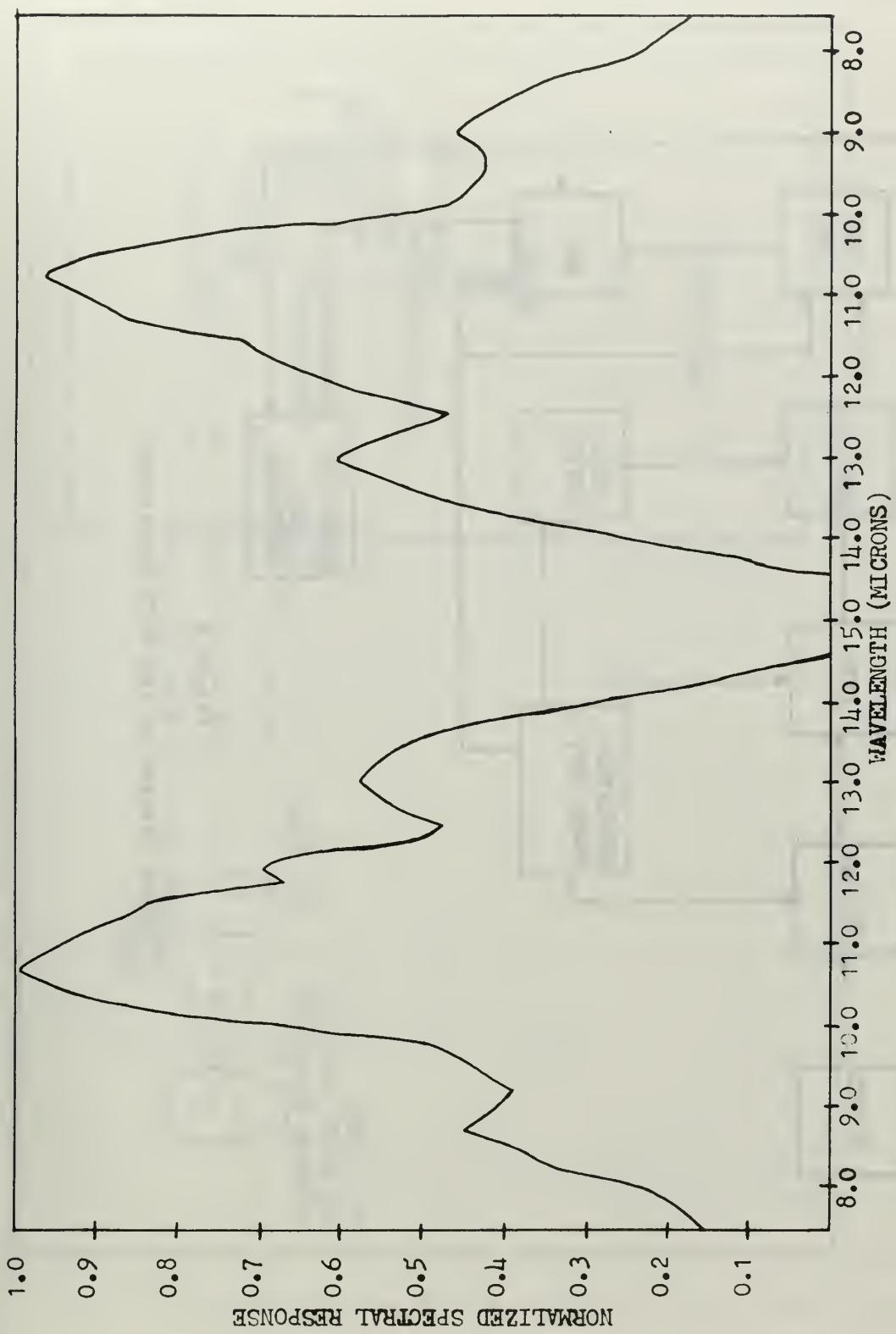
Figure 5

Relative Spectral Response of the NOTS Spectrometer
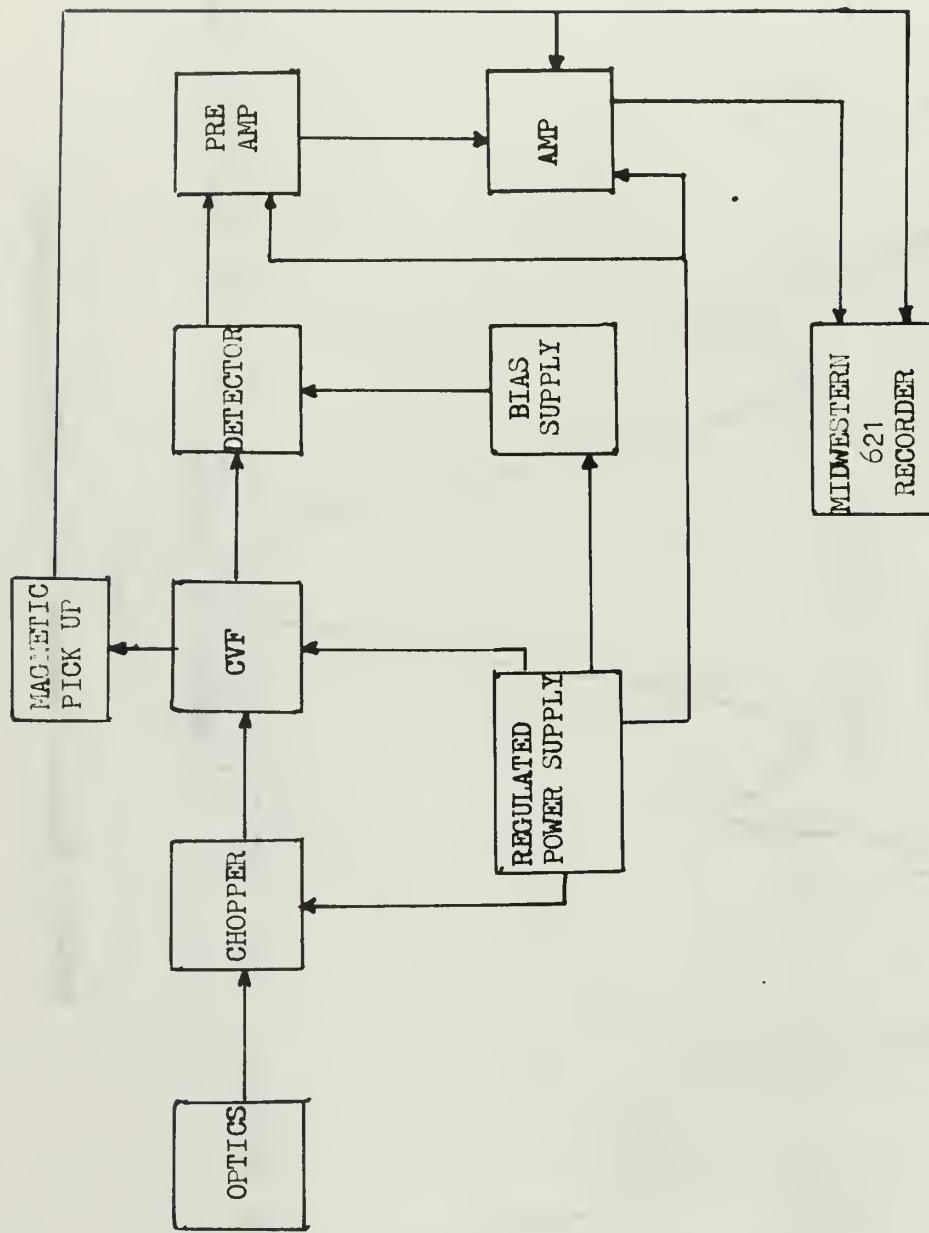
Figure 6

Block Diagram of the NOTS Spectrometer
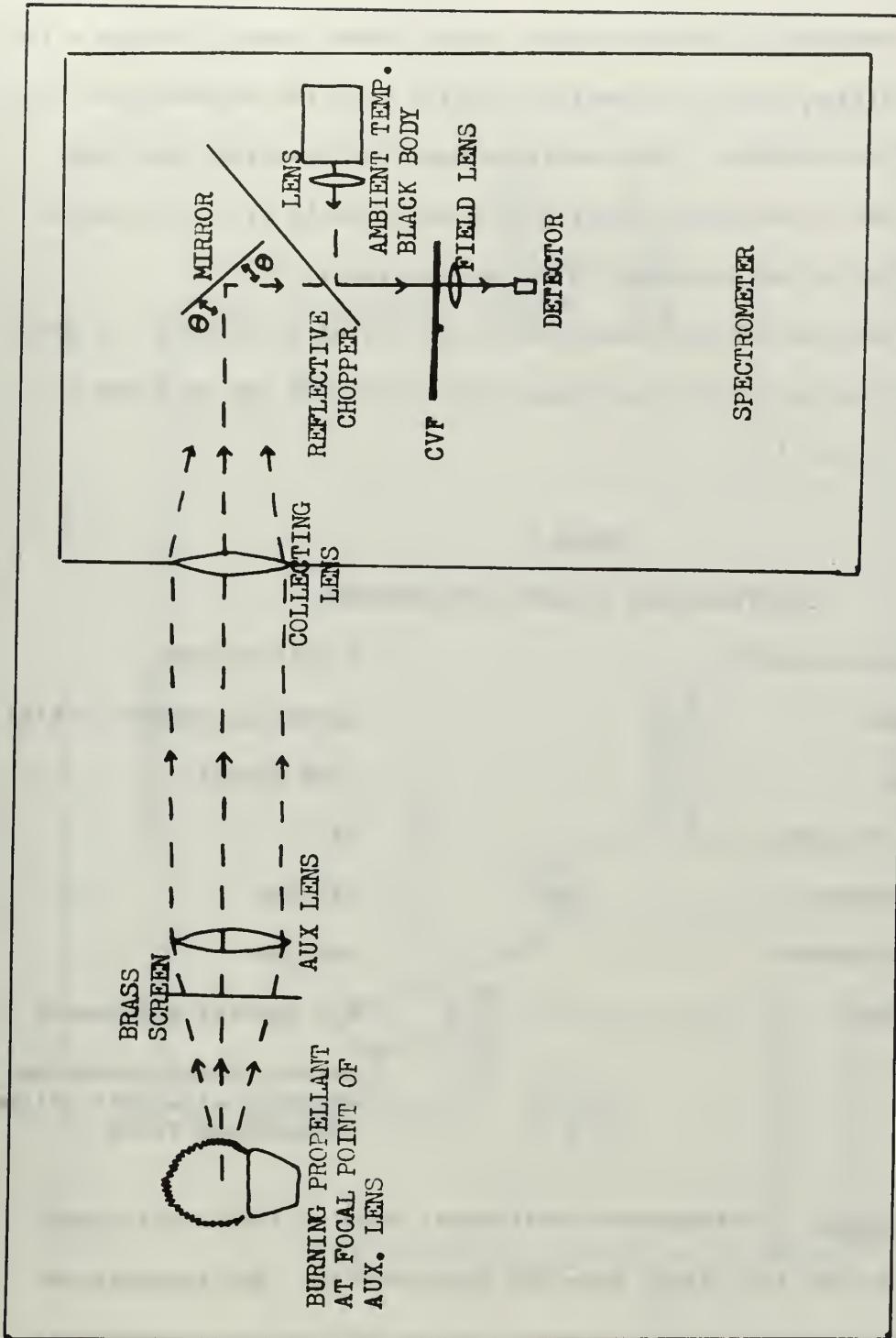
Figure 7

Optical Diagram for Experiment

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The detector for the spectrometer is mercury doped germanium. Since this detector must be operated below 40°K, it was housed in its own dewar. The detector is biased from a central power supply through a low noise preamplifier, which is capacitor coupled with the detector, and then is fed into an amplifier. The amplifier has four available gain settings which may be selected manually or automatically (1). The output from the amplifier was recorded on an oscillograph.

Specifications for the spectrometer are listed in Table 1. A more complete description of the instrument and of the CVF may be found in references (1) and (7).

TABLE 1

SPECIFICATIONS OF NOTS SPECTROMETER

Spectral range scanned	7.5-15 microns
collector lens	germanium aspheric (f/2)
aperture stop	.090 inches
total field of view	52'
chopping frequency	525 cps
electronic bandwidth	160 cps
scanning speed	2.5 spectra per second
detector	mercury doped germanium operated at liquid helium temperature (4°K)

b. Recorder: A Midwestern Instruments model 621-HT oscillograph was used to record the signal from the spectrometer. The recorder employs standard Midwestern galvanometers to record traces on photosensitive paper. Both Dupont MRK 010 Lino-Writ and Kodak Linagraph direct print paper were used for this experiment. A maximum of four inputs to the recorder were available from the spectrometer. Since no movie films

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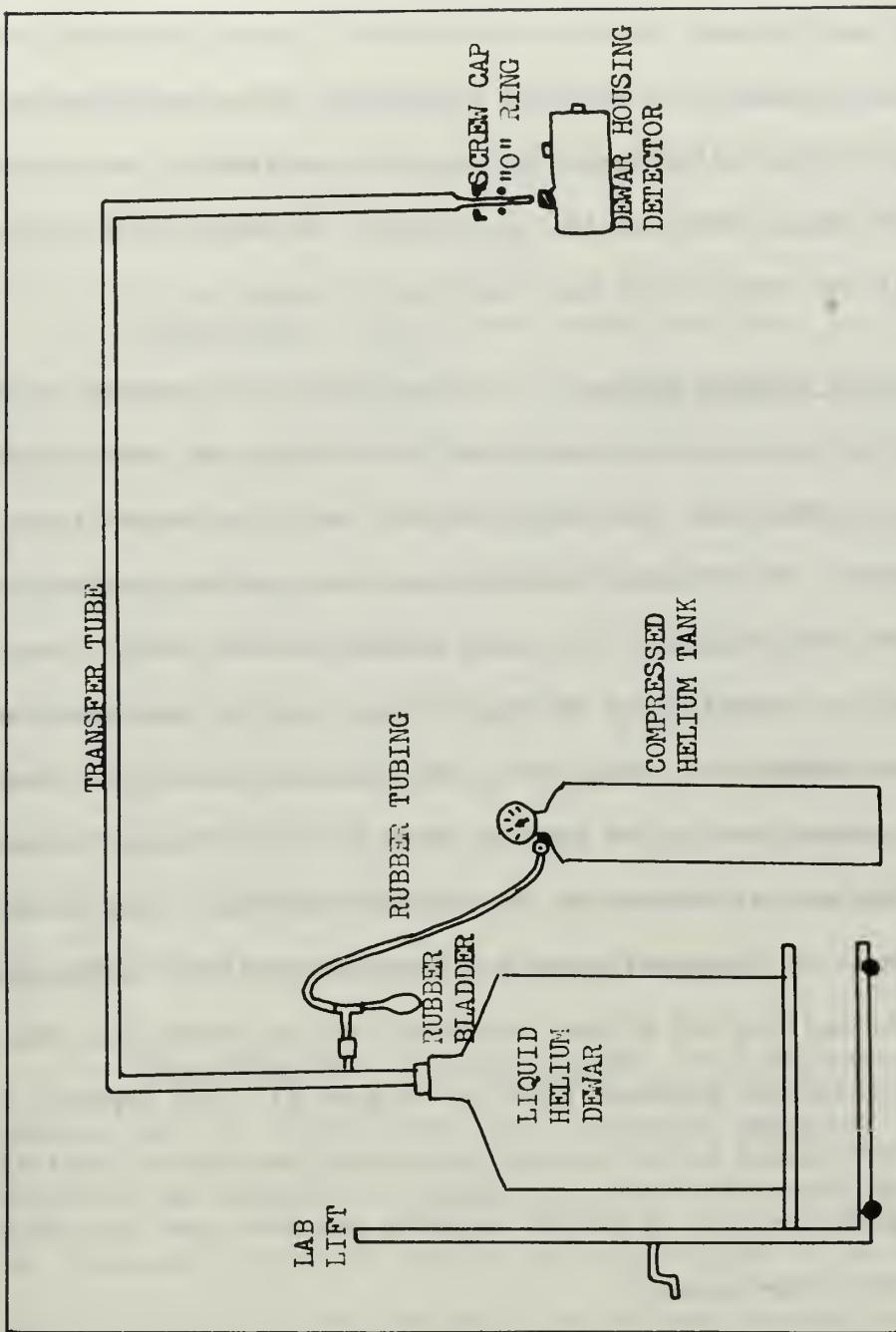
Figure 8

Helium Transfer System

were made of the experiment the camera timing pulse input was not used. The three inputs used for the experiment- timing pulse, gain setting, and amplified detector signal-were connected to the recorder by alligator clips at the terminals located on the top of the unit. The recording speed of the oscillograph could be varied from a paper speed of 0.3 to 60.0 inches per second (8). For this experiment the recording speed was set to give a recording length of about 15 centimeters for each complete rotation of the CVF (7.5-15-7.5 microns). A slight drift in recording length was experienced and could not be corrected.

c. <u>Detector Cooling System</u>: In order to keep the detector at operating temperature, a constant transfer of helium into the dewar housing the detector was required. The liquid helium was stored in a large (25 liter) dewar. An evacuated transfer tube was used to transfer the helium from the large dewar to the dewar housing the detector. Pressure to effect the transfer was obtained from a tank of compressed helium gas. A rubber bladder was connected to the transfer tube at the same point as the pressurized helium tank by using a "T" fitting. The rubber bladder provided manual control of the transfer operation when it was required. A vent on the dewar housing the detector allowed helium gas, produced by the boiling off of the liquid helium, to escape from the dewar and prevented any pressure build up (Figure 8). The appearance of the "feather" caused by the venting helium gas provided an optical means of checking the rate of helium transfer and also gave an indication of detector temperature.

d. <u>Ignition System</u>: An adjustable Variac Auto-transformer, type W10MT, manufactured by the General Radio Company was used as a power source for igniting the propellants. The Variac was plugged into

standard 115 volt AC. A standard knife switch was used to close the ignition circuit. Leads from the switch were connected to both ends of a 0.020 inch diameter nichrome wire. The nichrome wire was bent into a shape that allowed it to contact the top and two sides of the propellant cube (Figure 9). A voltage setting of ten volts on the Variac was found to be adequate to achieve ignition of the propellant. The nichrome wire broke during the first second of propellant combustion and did not contribute significant emission to the spectral record obtained.

e. <u>Propellants</u>: Three basic propellants were provided by the Naval Ordnance Test Station, China Lake, California. The chemical composition of the three propellants was similar except for aluminum content. Propellant A had a small percentage of aluminum, propellant B a larger percentage, and propellant C had no aluminum content and was used as a control. The propellants were cut into 1/2 inch cubes for firing and also into 1/2 inch by 1/2 inch by 1 inch pieces. It was found that the larger size pieces did not give a more intense spectrum but did burn longer than the 1/2 inch cubes. The actual chemical composition of the propellants may be obtained from the Naval Postgraduate School (11). The propellants were ignited and burned in small laboratory crucibles.

f. <u>Miscellaneous</u>: A Tetronix Model 565 oscilloscope was used to visually monitor the detector signal from the amplifier. The sweep of the scope was externally triggered by the timing pulse so that the signal displayed started at the 7.5 micron position of the scan. The timing pulse was taken off the amplifier and was the same as the timing pulse recorded on the oscillograph.

A three inch germanium lens with a focal length of 5.73 inches was used to focus the spectrometer on the target. The germanium collecting
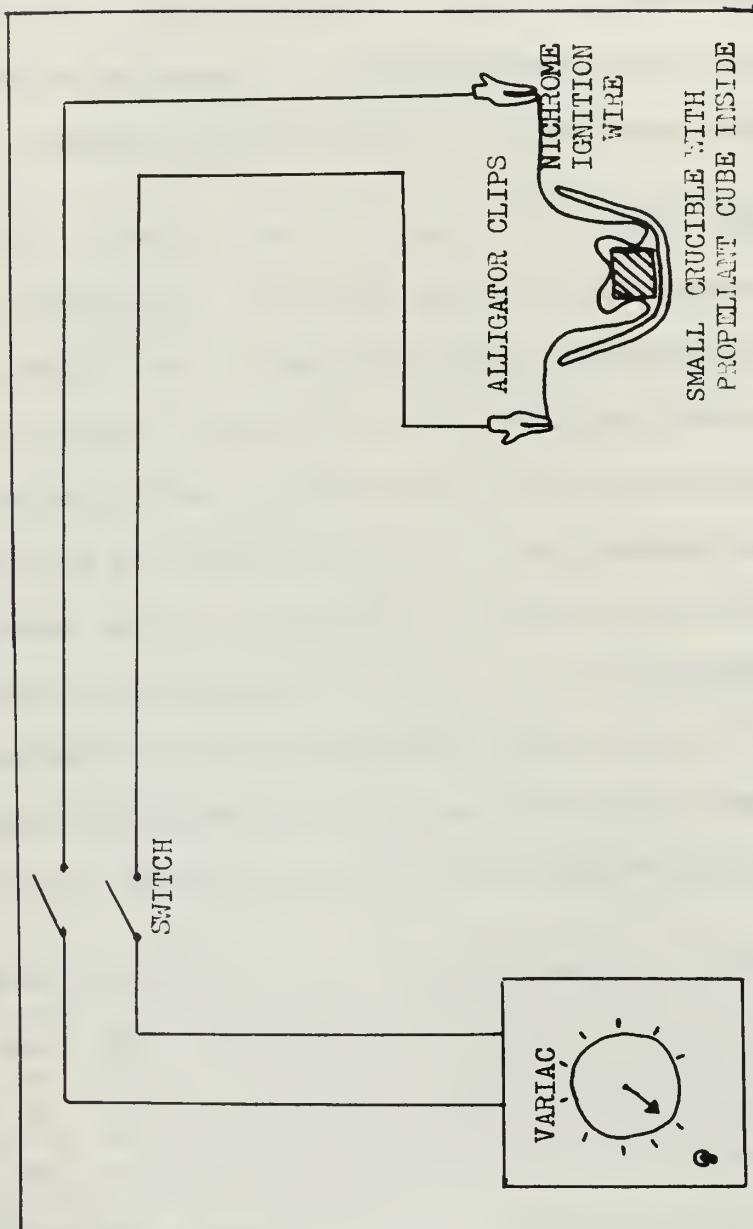
Figure 9

Ignition System

lens of the spectrometer was set at an infinite focal length; therefore, when the target was set at the focal plane of the auxillary lens and when the spectrometer lens was optically aligned with the auxillary lens, the maximum radiation from the target would fall on the detector. The auxillary lens was protected from the scattering of bits of burning propellant by a 1/16 inch mesh brass screen (Figure 7).

A blackbody source manufactured by the Barnes Engineering Company was used to calibrate and also to align optically the spectrometer. An aperture opening of 0.881 inches was used for the blackbody. This aperture agreed well with the 0.90 inch aperture stop on the spectrometer. Although the blackbody could be adjusted for temperature, the 600°C position was used for calibration since it was felt that at this temperature the emission from the blackbody would most closely match the emission from the burning propellant in intensity.

A vacuum tight combustion bomb was designed and constructed to obtain spectral data on propellant combustion at low pressure. Although the bomb was not used in this experiment it may be used in later experiments at the Naval Postgraduate School and its description is given in Appendix I.

3. Experimental Procedure

The spectrometer was placed on three laboratory jacks which were positioned on a laboratory cart. The blackbody source was positioned in the hood. The temperature scale on the blackbody was set for 600°C and the blackbody was turned on. It usually required about one hour for the blackbody to stabilize at the 600°C temperature.

The spectrometer was then optically aligned and focused on the blackbody. A centimeter rule and a level were used to make the vertical alignment exact. The horizontal alignment was made by "eye" and

later readjusted by moving the spectrometer horizontally until a maximum signal from the detector was seen. The auxillary lens was placed in position using the centimeter rule to position the blackbody at the focal plane of the lens. The position of the lens was later readjusted by peaking the detector signal.

The dewar in which the detector was housed was then removed from the spectrometer, flushed with compressed helium gas to remove any accumulated moisture, and then cooled with liquid nitrogen. When the interior temperature of the dewar was low enough to start retaining liquid nitrogen all the nitrogen was shaken out of it. The dewar was then mounted back on the spectrometer and all its apertures corked in order to prevent any condensation of water inside. The helium transfer tube was then connected to the dewar, all corks removed, power applied to the spectrometer, and helium transfer was begun, squeezing the rubber bladder. The appearance of the "feather" caused by the condensation of water vapor by the helium gas escaping from the vent on the dewar gave a good indication of the rate of helium transfer.

The amplifier gain control was always set at maximum gain during the cool down process. A sharp increase in the detector signal above noise level on the oscilloscope indicated that the detector was down to operating temperature. The appearance of the "feather" was also monitored as it sharply increased in density as soon as liquid helium was being retained in the dewar. This usually occurred a few seconds before the rise in signal strength was observed on the oscilloscope. When it was determined that the detector was at operating temperature the spectrometer alignment was readjusted to give a maximum signal on the oscilloscope. The blackbody source was then removed from the hood and propellant firing begun.

The first few propellant firings were used to find an optimum gain setting on the amplifier (one that would give the maximum deflection on the recording paper without saturating the amplifier). When the correct gain setting had been determined the blackbody source was again set into position and its spectrum recorded at that gain setting. If the gain setting proved to be too low to give adequate resolution for the blackbody spectrum the spectrum was also recorded at a higher gain setting. The blackbody was then removed from the hood and spectral records were recorded for the three propellants. The temperature of the near ambient temperature blackbody source (T_1) was monitored throughout the firing sequence and was readjusted if it happened to drift. Care was taken to insure that the propellants were placed in the focal plane of the auxilliary lens and in the same horizontal position for each firing in order to keep the optics for each spectral record constant.

4. Calibration

The spectral radiance (N_λ^{BB}), as a function of wavelength, for a blackbody at known temperature may be found using the Planck equation. The spectral response (R_λ) of the spectrometer for any given wavelength can then be obtained by measuring the deflection (S_λ^{BB}) of the oscillograph at that specified wavelength and using equation 1 (9).

$$1. \quad R_\lambda = \frac{S_\lambda^{BB}}{N_\lambda^{BB}}$$

If a source of unknown spectral radiance is then placed at the same point as the blackbody and the optical geometry kept constant, the spectral radiance of the unknown (N_λ^T) can be found for any specified wavelength by using equation 2 (9). (S_λ^T) is the deflection caused by the unknown.

$$2. \quad N_\lambda^T = \frac{S_\lambda^T}{R_\lambda}$$

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In order for equation 2 to be valid the spectrometer must be free from any electronic drifts which would alter the spectral response between the time the two measurements are made.

Equations 1 and 2 may be combined to form equation 3, which is easier to use for point-by-point data reduction.

$$3. \quad N_\lambda^T = \left(\frac{S_\lambda^T}{S_\lambda^{BB}} \, N_\lambda^{BB} \right)$$

In this experiment the spectrometer was checked for drifts by taking two spectral records of steady state sources over a relatively long period of time (one minute). The two steady state sources selected were the 600°C blackbody and a sheet of black paper placed over the collecting lens of the spectrometer. Results showed that although there was a slight change of the spectral record with time the error introduced by electronic drift was negligible compared to errors introduced during data reduction. A spectral record of the blackbody source at the same temperature was also taken between propellant firings and its spectrum was found to agree well with the spectrum taken earlier.

The effect of the brass screen in front of the auxillary lens was found to decrease its effective area by 25%. Since N_λ^{BB} was measured without the screen in place the right hand side of equation 3 was multiplied by a corrective factor of 1.33.

A scaling factor of 0.53 was applied to (S_λ^{BB}). This scaling factor was necessary because the spectrum of the blackbody source taken at the same gain setting as the propellants was too small. A spectrum taken at a higher gain setting was therefore used. The deflection of the two spectra at 10.7 microns was then measured and the scaling factor calculated.

5. Reduction of Data

The numerous spectral records for each of the three propellants were compared to the spectral record of the blackbody source. Except for the peak in deflection at 7.5-9.0 microns, which was clearly much higher for propellant C, no large deviations were directly evident. Although several small differences were noticed between the propellants, it was decided that only a careful analysis of the data from the three propellants and the blackbody taken under identical circumstances would show if any significant energy bands were present in the "atmospheric window" region. Two complete spectral records for each propellant taken under identical conditions were selected. Each spectral record consisted of between three and ten spectral scans (7.5-15.0-7.5 microns).

The recording paper used for the experiment was light sensitive. Since the traces on it would fade with continued exposure to light, overlays of each spectral scan were made on tracing paper (Appendix II). The two sets of overlays from each propellant and the single overlay for the blackbody source were then averaged to get a composite spectrum for each source. The averaging process was done by picking a spectral scan for each propellant that appeared to be the best representative sample, tracing it on graph paper and then comparing it to each of the other spectral scans for that source. Corrections were made to the representative spectral scan whenever a majority of the other spectral scans differed from the sample. Although this method was somewhat subjective and any time variation in the emission from the propellants was lost, it was felt that any significant point in the spectrum that was consistantly present would appear in the composite spectrum. This

method also helped to even out any unevenness in emission caused by uneven burning or momentary "sputtering" of the propellant. Since the scan time for a single spectral scan was rather long (0.8 seconds) it was felt that the latter consideration was an important one.

The spectral records chosen for propellant B were found lower in intensity than those for either of the two other propellants. Since the other spectral scans taken of propellant B indicated that it was at least as intense in certain regions as propellant A a scaling factor of two was used to correct for its intensity. The scaling factor is approximate and was derived from comparing spectral scans taken of propellant B under different conditions but it is felt that if it is in error it errs on the low side. The lower intensity of these two spectral scans was probably due to incorrect positioning of the propellant with regard to the focal plane of the spectrometer. Since they were taken one after another it is highly possible that the same error was made twice.

A plot of the composite spectrums of the three propellants was then made (Figure 11). A separate plot of the composite spectrum of the 600°C blackbody source was also made (Figure 10). The deflection, from the zero line at significant wavelengths was then read from the composite plots for each propellant and compared to the scaled deflection of the blackbody source at the same wavelength $\left(\frac{S_\lambda^T}{S_\lambda^{BB}}\right)$. Since each spectral scan included the wavelength region from 7.5 to 15.0 microns twice (one spectrum for each side of the filter wheel), the two $\left(\frac{S_\lambda^T}{S_\lambda^{BB}}\right)$ ratios for the same wavelength were averaged to give $\left(\frac{S_\lambda^T}{S_\lambda^{BB}}\right)^*$. The $\left(\frac{S_\lambda^T}{S_\lambda^{BB}}\right)^*$ ratio versus wavelength was then plotted for each of the propellants, (Figure 12).
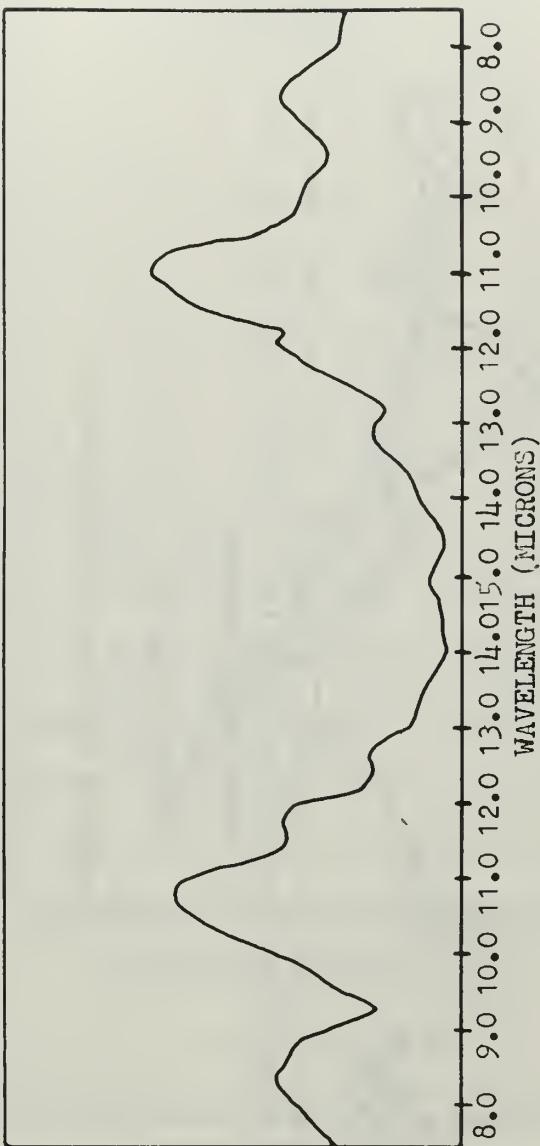
Figure 10

Composite Spectrum of 600°C Blackbody
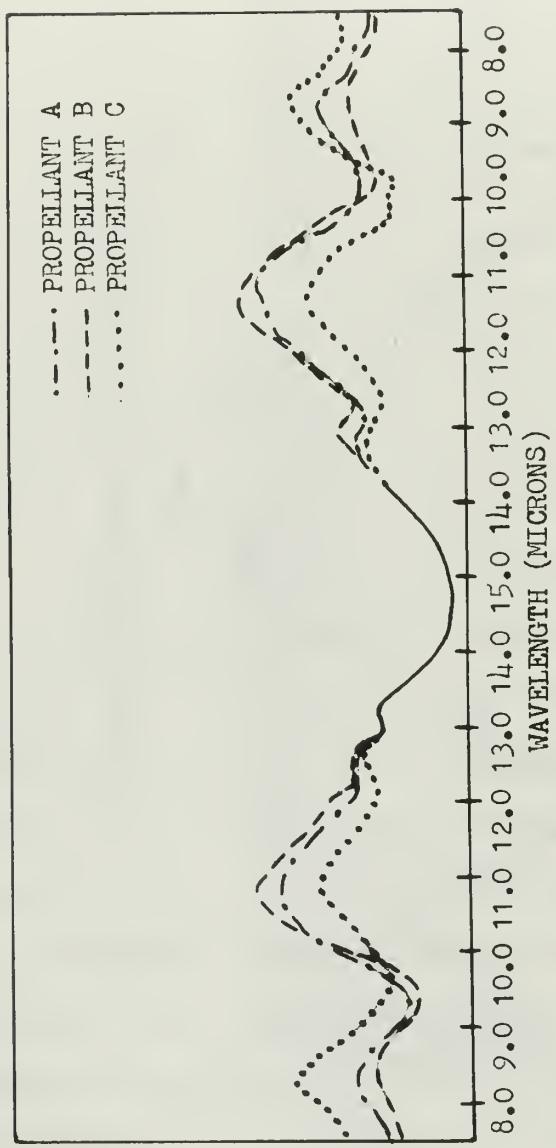
Figure 11

Composite Spectrum of Propellants
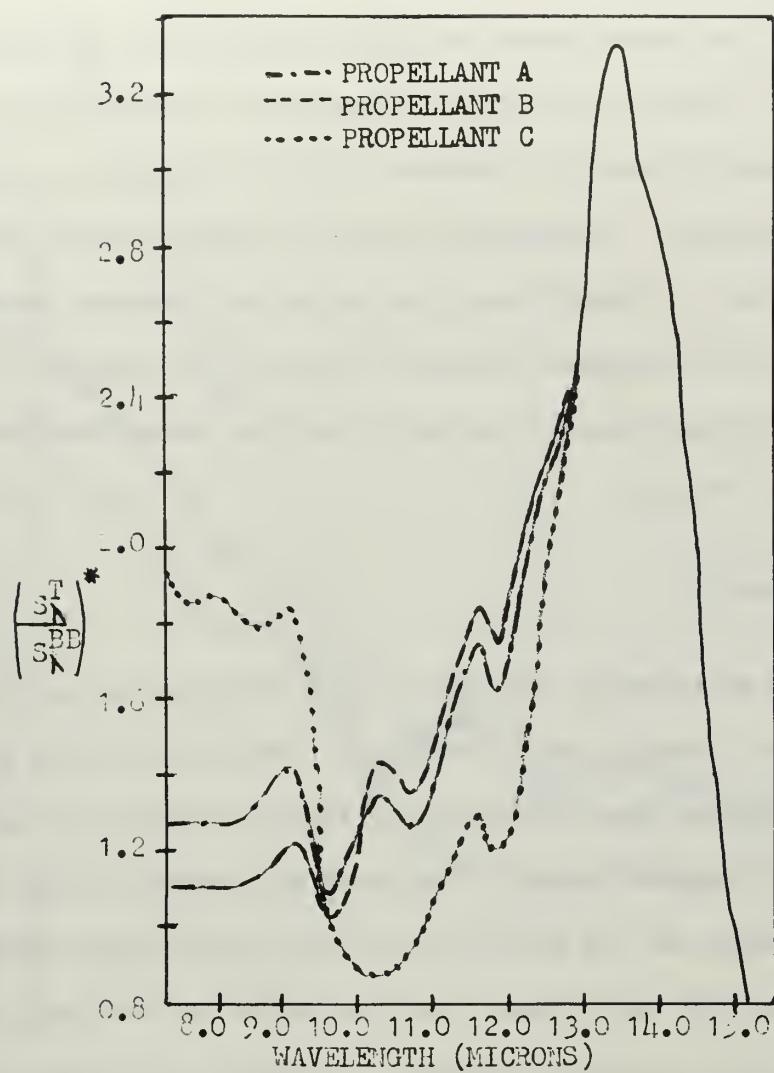
Figure 12

Scaled Deflection of the Propellants Compared
to the Scaled Deflection of the 600°C Blackbody
Versus Wavelength

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N_λ^{BB} was then computed for the 600°C blackbody source using a black-body slide rule made by the General Electric Company. N_λ^{T*} for each propellant at significant wavelengths was then computed and the results plotted (Figure 13). Since the effect of atmospheric absorption was not taken into account, Figure 13 represents a plot of apparent spectral radiance versus wavelength. The peak at the 10.3 micron position for propellants A and B was not significantly effected by atmospheric absorption since it is in the "atmospheric window" region of the infrared spectrum and since the spectrometer was only about one meter from the propellant at time of firing.

6. Discussion of Results

If Figure 13 is an accurate depiction of the actual emission from the three propellants, several points stand out. The most intense emission, in terms of apparent spectral radiance, for all three propellants is seen in the 7.5-9.5 micron region. This peak is probably caused by H_2O emission. The height of the peak for the three propellants agrees well with predictions. It can be seen that the height of this peak for propellant C, which had no aluminum content, is significantly higher than the corresponding peaks for propellants A and B. It also appears that the height of the H_2O peak for propellant A is higher than the peak for propellant B. The height of the H_2O peak for each propellant appears to be inversely proportional to the aluminum content of the propellant. Since the oxygen content in each propellant probably would be apportioned first to the formation of aluminum oxide and then to the formation of H_2O, the results agree well with theory.

The most significant factor in the appearance of Figure 13, is the peak in apparent spectral radiance at about 10.3 microns for propellants
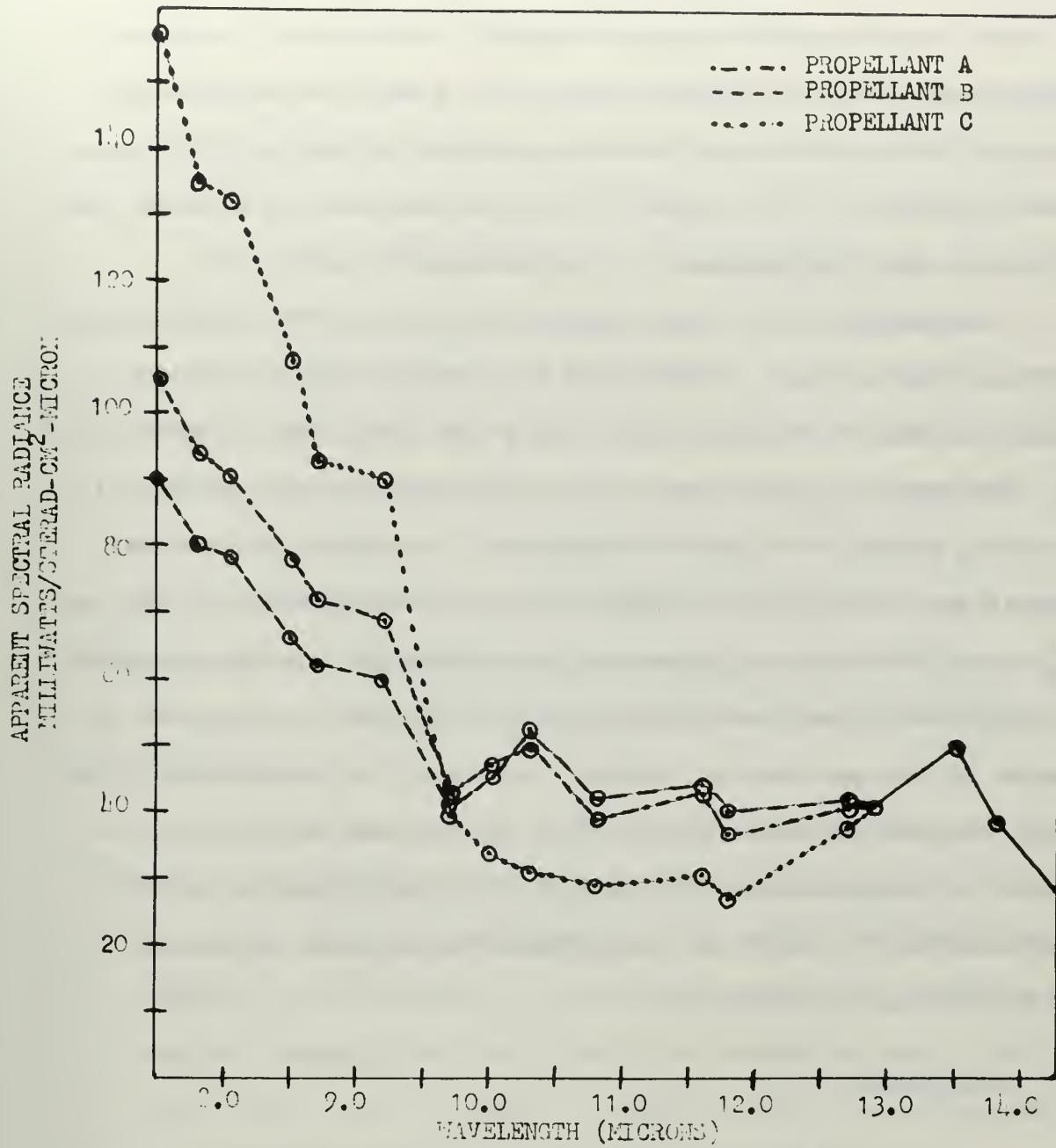
Figure 13

Apparent Spectral Radiance Versus Wavelength

A and B, both of which contained aluminum. The height of this peak is significantly higher than the emission from a 600°C blackbody in this region. No trace of a peak in this region can be found in the emission from propellant C. From Figure 3 it may be seen that the emission from aluminum oxide lies precisely in this wavelength region.

The spectra of all three propellants in the 11.0-15.0 micron region are similiar in shape. A difference in intensity, however, exists between the spectra of propellants A and B and the spectrum of propellant C. The peak in spectral radiance for all three propellant at 13.5 microns is thought to be due to CO_2 emission. Theoretically this peak should show the same distribution with regard to propellants as did the H_2O peak. It is also apparent that the intensity of the spectra should continue to increase until approximately 15 microns. The spectral response of the spectrometer, however, as well as the transmission of the auxillary lens decreases rapidly after 13.5 microns and the effect of noise on the appearance of the spectrum is probably masking any differences that may exist and also produces the decrease in spectral radiance after 13.5 microns.

7. Conclusions

The amount of error introduced into the final results by the data reduction technique used can only be estimated. It is felt that the values for apparent spectral radiance as read from Figure 13 may be in error by as much as a factor of ten. The error, however, is more likely to be toward the low side and the values for the spectral radiance are probably higher than reported. The error in the position of the peaks with regard to wavelength may be as high as $\pm$ 0.5 microns. The general

shape of the spectral radiance versus wavelength curves, however, is thought to be accurate. Propellant C does have a more intense water band than either propellant A or B and the emission from propellants A and B is more intense than that for propellant C at about 10.3 microns.

The results obtained are not to be considered as an exact description of the emission of the propellants. They do add impetus to the need for other experiments in this region. If the results of more accurate experiments agree with the results obtained here, the evidence for the aluminum oxide peak would be substantial. Measurements of emission from missile propellants containing aluminum are now being conducted at the Naval Postgraduate School using a Warner Swasey rapid scanning spectrometer. The publication of results from this experiment should give more accurate information on emission in the 7.5-15.0 micron region.

If the presence of the aluminum oxide peak is confirmed, the next step in experimentation would be to compare the energy of this peak with the energy of the H_2O and CO_2 peaks in the shorter wavelength spectral regions (2.0-5.5 microns). A calculation could then be made to establish how much energy in each region would be transmitted over a long atmospheric path (i.e., 100 miles). A decision could then be made on which region offers the best chance for early missile detection.

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APPENDIX I

Combustion Bomb

TABLE 2

SPECIFICATIONS OF THE COMBUSTION BOMB

|	
main body	manufactured from 1/8" stainless steel cylinder
end and face plates	manufactured from 1/4" stainless steel plates
top cover plate	manufactured from 3/8" stainless steel plate
windows	two with an inside diameter of 5/8", two with an inside diameter of 1 1/4"
window material	germanium, windows can also be sealed off copper discs when not in use
sensor ports	two 3/8" sensor ports, one used for ignition leads, one used for evacuating the bomb, ports may be sealed off with copper discs when not in use
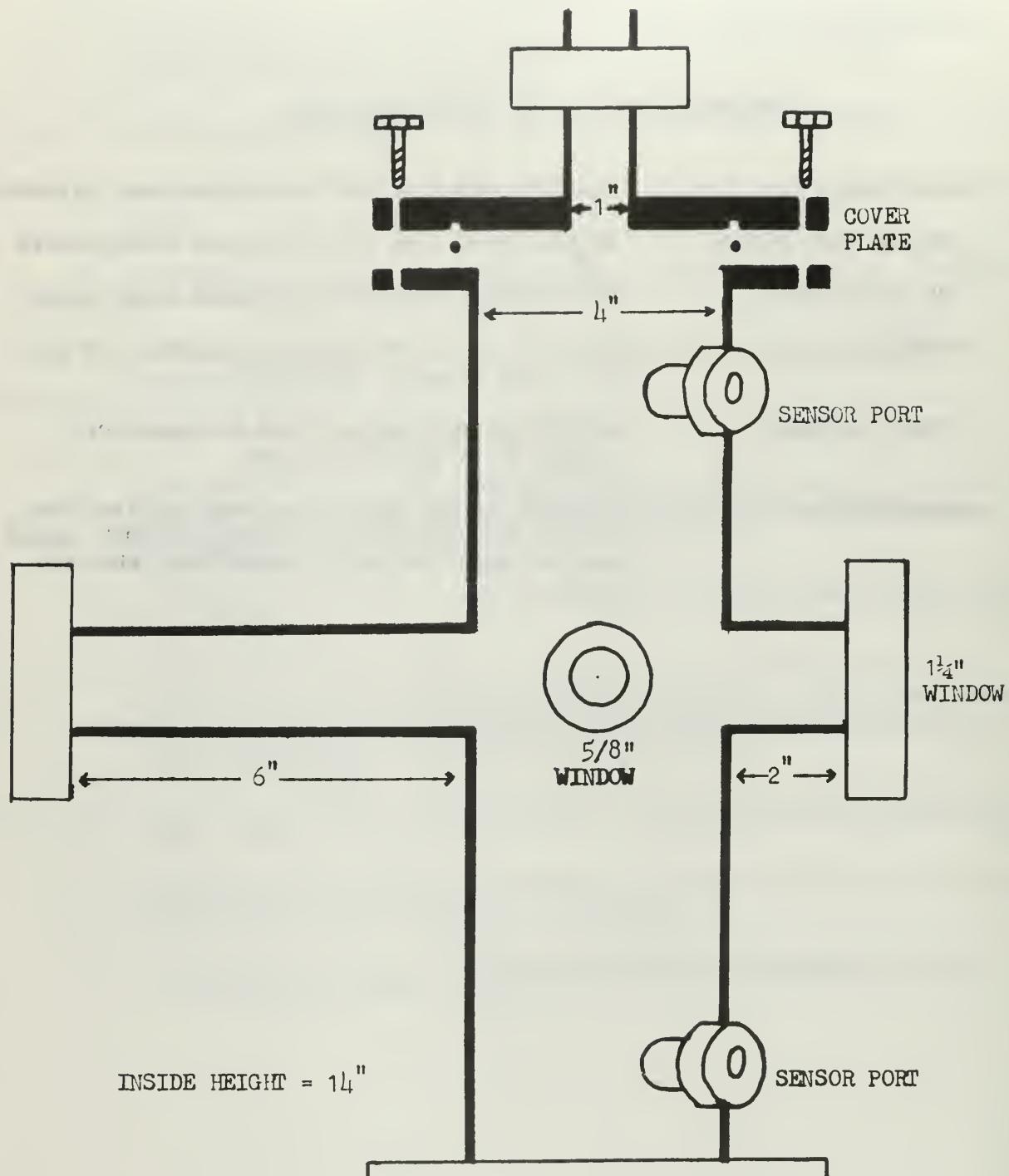
Figure 14

Combustion Bomb

COPPER
WASHER

GERMANIUM WINDOW

"O" RING SEAL

SLEEVE
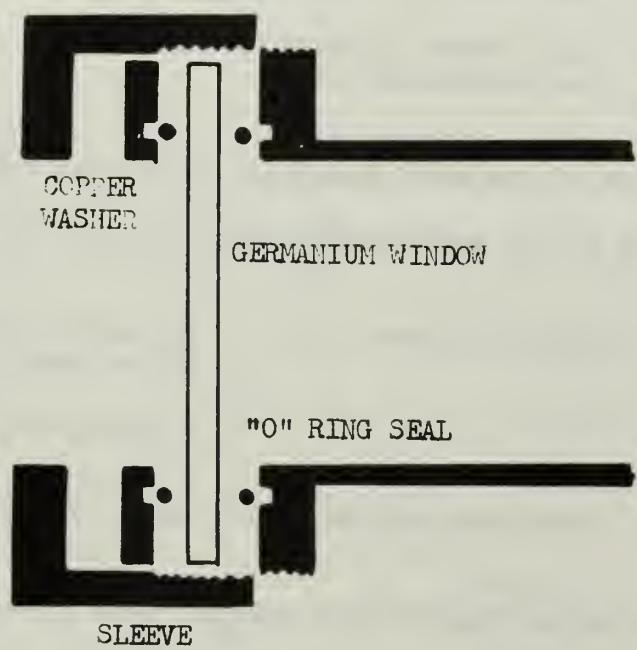
Figure 15

"O'Dea Seal"

43

Spectra of Propellants and 600°C Blackbody Source

The spectra of propellants A, B, and C were taken with the following settings on the spectrometer and under the following conditions:

Amplifier Gain   2 Low

T_1 1.60 millivolts (40°C)

Auxillary lens and brass screen in place.

Spectrometer focused on a point 12.5 cm above the propellant cube.

The spectrum of the 600°C blackbody source was taken with the following settings on the spectrometer and under the following conditions:

Amplifier Gain   Not applicable as scaling factor used

T_1 1.60 millivolts (40°C)

Auxillary lens in place, screen not used

In the following figures each spectral scan is numbered with regard to its relative time placement during combustion. Within each spectral scan the time after ignition is increasing from right to left.
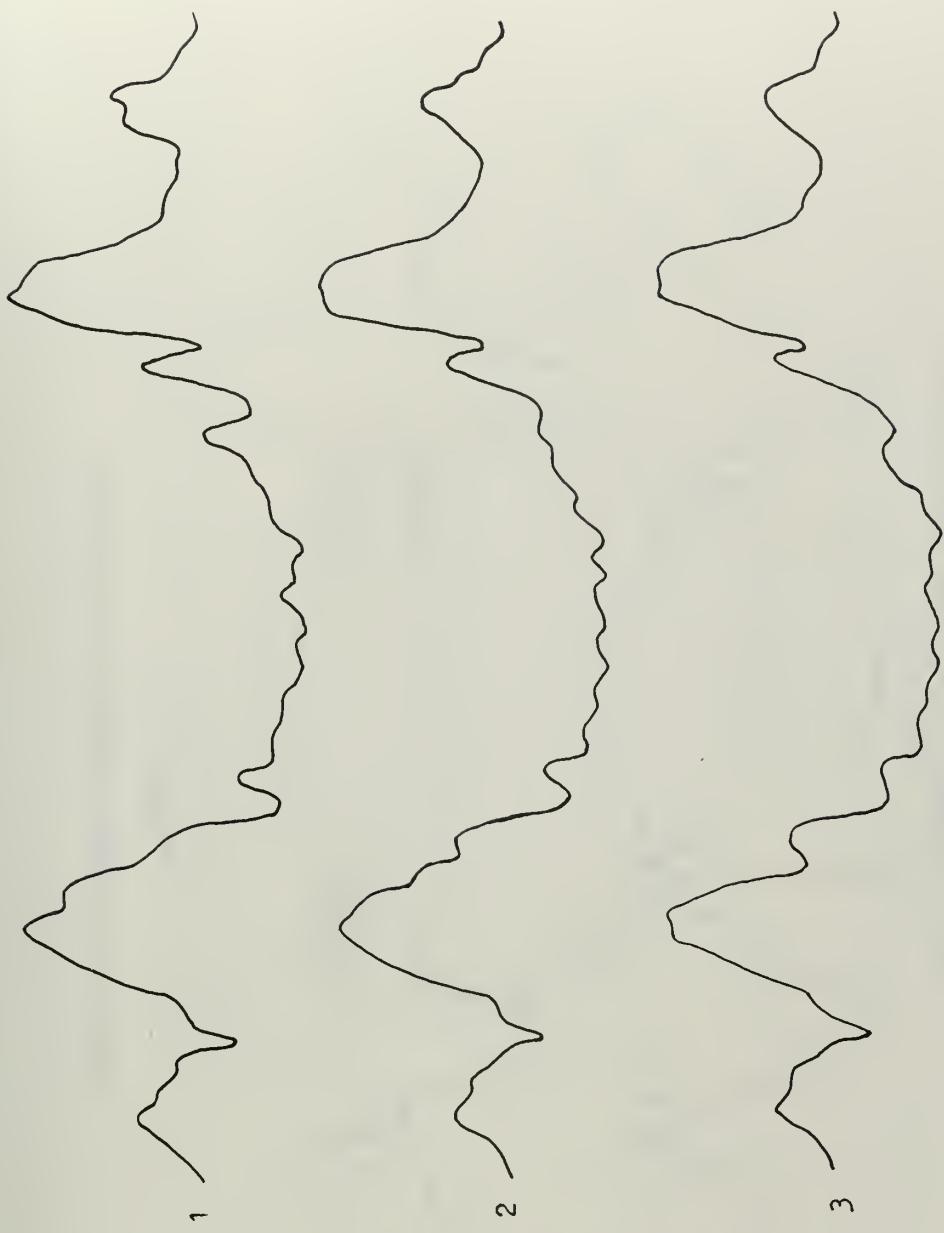
Figure 16

Spectra of 600°C Blackbody

45

Figure 17

Spectra of 600°C Blackbody (Continued)
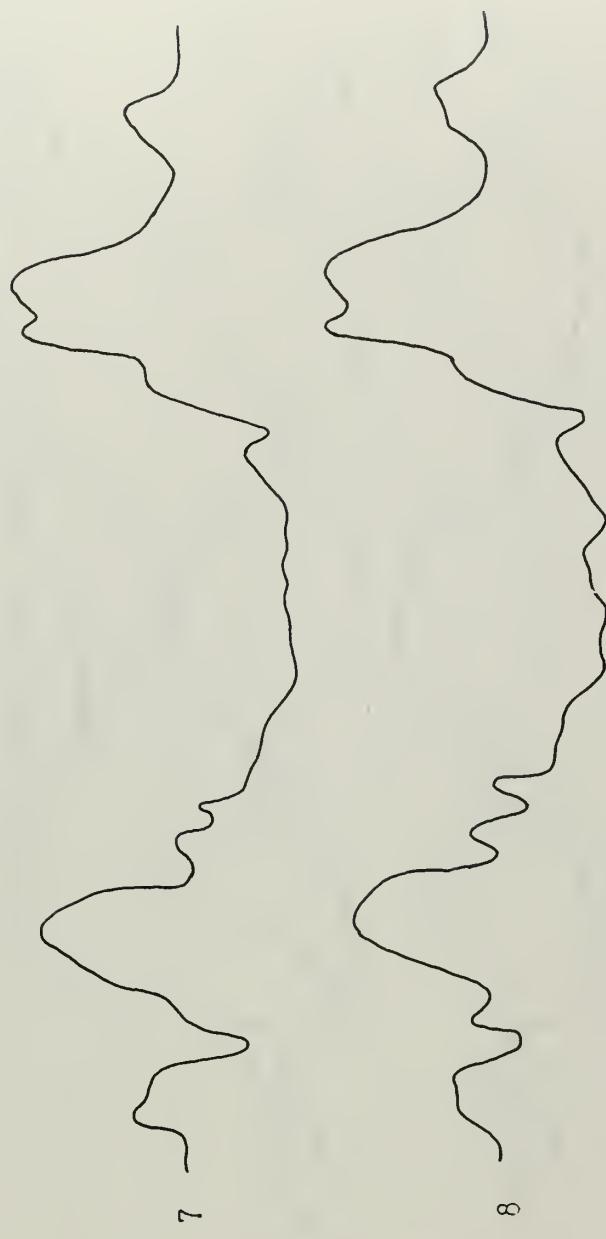
Figure 18

Spectra of 600°C Blackbody (continued)

Figure 19

Spectra of Propellant A (run 6-1)
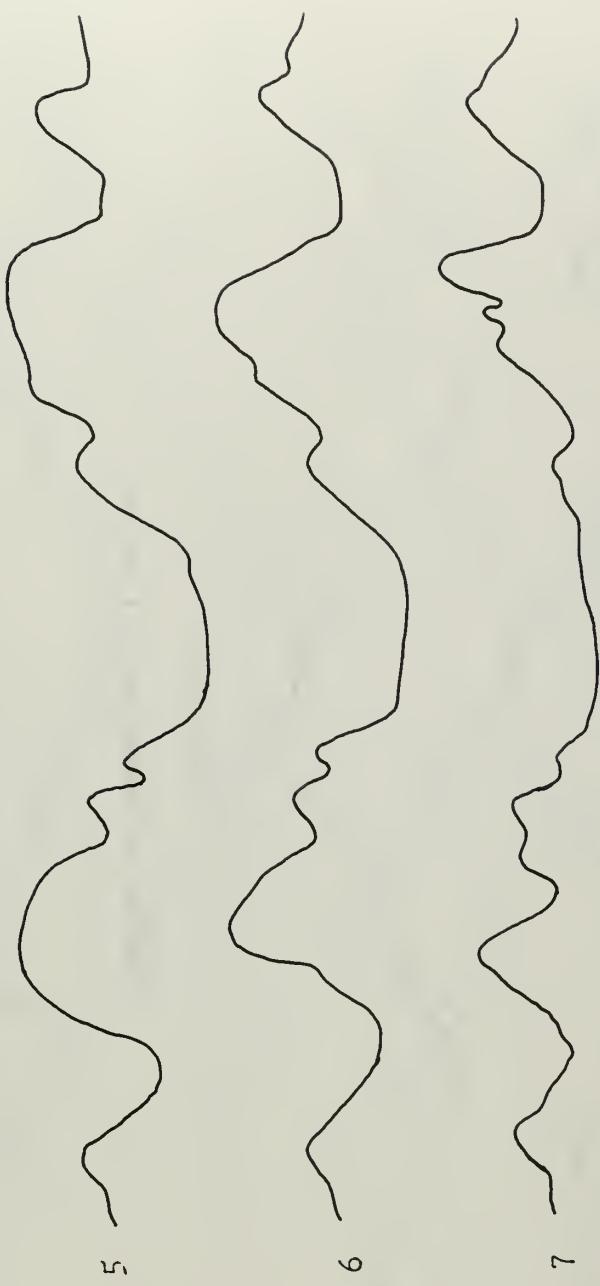
Figure 20

Spectra of Propellant A (run 6-1 continued)

Figure 21

Spectra of Propellant A (run 6-2)

50
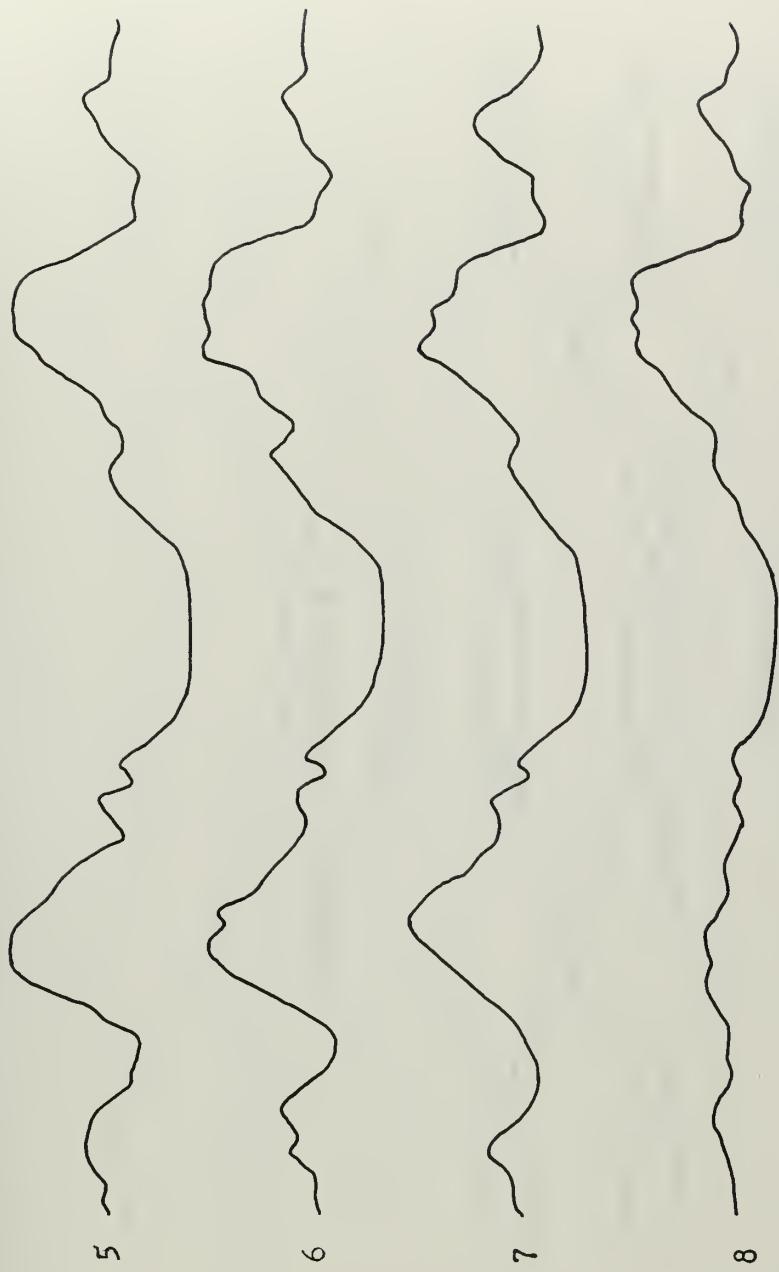
Figure 22

Spectra of Propellant A (run 6-2 continued)

51
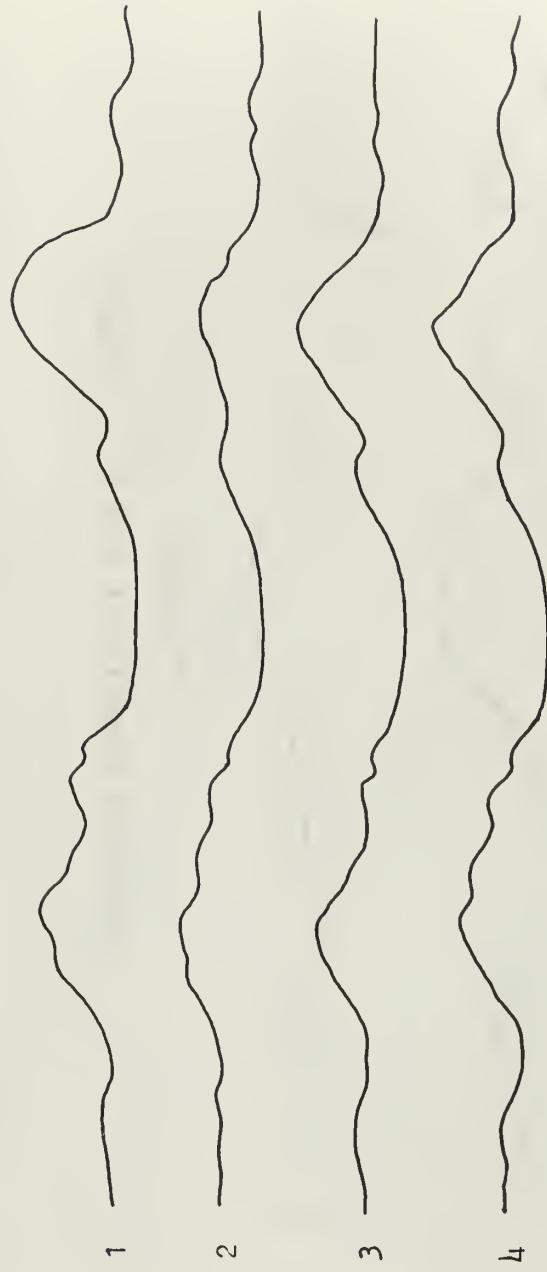
Figure 23

Spectra of Propellant B (run 2)

52
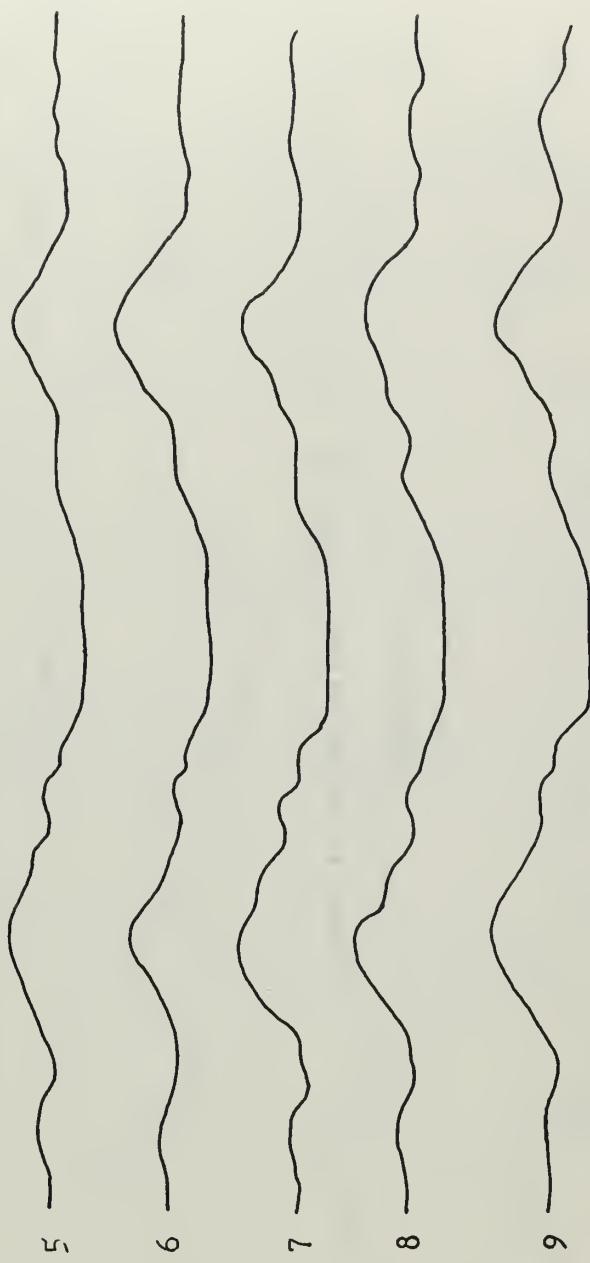
Figure 24

Spectra of Propellant B (run 2 continued)

Figure 25

Spectra of Propellant B (run 3)

54

Figure 26

Spectra of Propellant C (run 5-1)

55
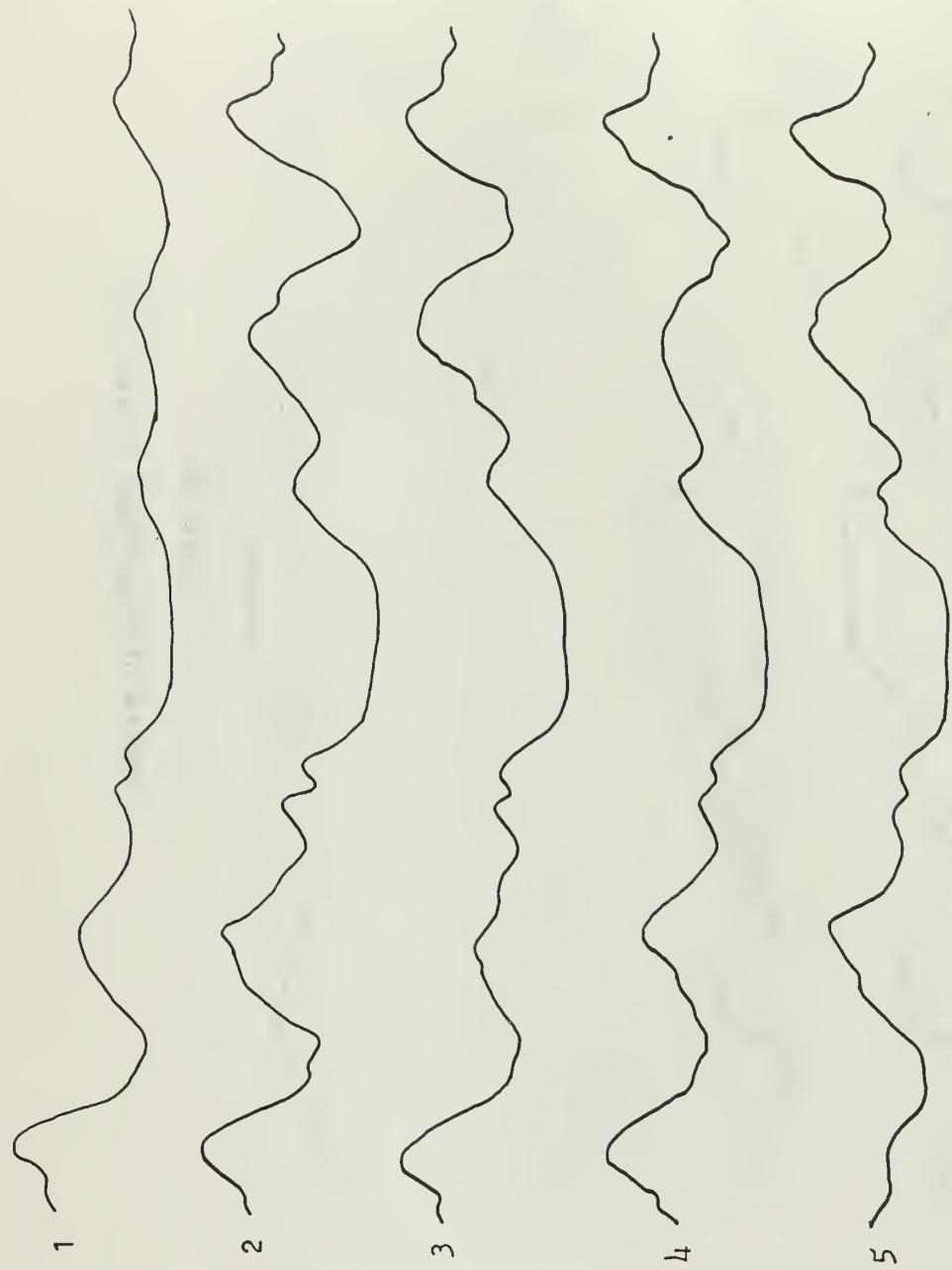
Figure 27

Spectra of Propellant C (run 5-2)

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13. ABSTRACT

The effect of aluminum in solid propellants on the emission of combustion energy in the 7.5-15.0 micron region of the infrared spectrum was measured. The presence of an "atmospheric window" (8.0-13.0 microns) allows energy in this region to be transmitted over long atmospheric paths with minimal attenuation. The 7.5-15.0 micron spectra of three propellants, similar in composition except for aluminum content, were recorded on an oscillogram. The deflection of the oscillogram at certain wavelengths was then compared to the oscillogram of a $600^{\circ}C$ blackbody. The apparent spectral radiance for each propellant at these wavelengths was then computed. Results indicated that in the aluminized propellants a relatively intense band occurred at about 10.3 microns. No evidence for such a band was found in the control propellant which contained no aluminum. Results also showed that the intensity of the H_2O band was inversely proportional to the aluminum content of the propellant.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
SOLID PROPELLANT/SPECTRAL ANALYSIS						
IR SPECTRA/EMISSION						
ALUMINUM						
ATMOSPHERIC WINDOW						